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Management and demographic factors associated with seropositivity to transmissible gastroenteritis virus in US swine herds, 1989–1990

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Abstract

Serum neutralization testing was used to determine transmissible gastroenteritis (TGE) titers of up to 10 sows per herd (mean 8.7, median 10) for 392 herds that participated in the 3 month monitoring of sows and litters in the National Swine Survey. Of the sampled herds, 101 (25.8%) had sow seroprevalences of at least 80%, 79 (20.1%) had seroprevalences between 10 and 79%, and 212 (54.1%) were seronegative. For evaluation of risk factors for TGE seropositivity, analysis was restricted to herds with at least five tested sows and either 0% or at least 20% seropositive sows. In the logistic regression analysis, a herd was considered seropositive if at least 20% of sampled females had titers of 1:8 or higher ($n = 160$), and a herd was seronegative if all females had titers of under 1:8 ($n = 178$). Factors considered for inclusion in logistic regression models included breeding herd size, biosecurity measures, pig introductions and movements, and access of possible nonporcine reservoirs to the facilities with pigs. After controlling for the effects of season, number of samples tested and TGE vaccination history, large female breeding herd size (at least 500 sows compared with the reference category of 100–199 sows) and purchase of more than 25 pigs from non-specific pathogen free (SPF) herds were associated with significantly ($P < 0.05$) higher odds of herd seropositivity (odds ratios 4.9 and 3.9, respectively). There was some evidence ($P = 0.08$) of an increased risk of seropositivity when there were more than two swine herds within a 3 mile radius of the study herd.

Keywords: TGE; Risk factors; Serum neutralization testing; Survey; Swine

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1. Introduction

Transmissible gastroenteritis (TGE) is a highly contagious, viral disease characterized by vomiting, severe diarrhea, and mortality of up to 100% in pigs less than 2 weeks old. Pigs over 5 weeks of age often have milder clinical signs and mortality is usually less than 10–20% depending on the age at infection and the degree of passive immunity (Garwes, 1988; Bohl, 1989; Saif and Wesley, 1991). Control of clinical disease is difficult because there is no effective practical treatment and commercial modified-live and killed vaccines are of limited effectiveness in TGE-naive swine (Saif and Wesley, 1991).

Clinical episodes of TGE occur more frequently during colder months (Pritchard, 1982; Bohl, 1989; Saif and Wesley, 1991). This seasonal occurrence has been attributed to increased survival of the virus at colder temperatures (Siegel et al., 1991) and the tendency for pigs to develop diarrhea because of low or fluctuating temperatures. Pigs with diarrhea probably shed greater amounts of TGE virus than subclinically infected animals (Shimuzu and Shimuzu, 1978), and hence, challenge doses are probably greater also during winter months.

Two forms of TGE occur. Epizootic TGE generally develops when the virus is first introduced into a susceptible herd but is usually of short duration and no longer clinically evident after herd immunity develops. On the other hand, enzootic TGE occurs when virus persists in a partially immune herd into which susceptible swine are introduced (Bohl, 1989; Saif and Wesley, 1991). Recrudescence of clinical TGE often occurs in enzootically infected herds about 9 months after the first outbreak as offspring of susceptible sows are exposed to the virus. TGE recrudescence has been associated with breeding herd sizes of over 100 sows, the presence of finishing pigs in large herds, and the introduction of purchased gilts (Pritchard, 1987). Parity (parity 3 on farm 1, parity 1 on farm 2), the use of purchased versus homebred gilts, and the use of multiple boar matings increased the risk of TGE on two Illinois farms (Siegel et al., 1991), but to our knowledge there are no previous large-scale population-based studies that have quantified the risk associated with herd-level management factors.

The National Swine Survey was conceived and implemented by veterinarians in the United States Department of Agriculture: Animal and Plant Health Inspection Service: Veterinary Services (USDA:APHIS:VS), in collaboration with universities and producer groups, to estimate health and productivity parameters for swine in the United States. The objective of the present study was to use data from the National Swine Survey (NSS) collected between November 1989 and February 1991 to identify herd-level management and demographic risk factors for TGE seropositivity and quantify the magnitude of these risks.

2. Materials and methods

The sampling design used to collect data for the National Swine Survey involved multiple frames (areas and lists) and was multistaged (herds, farrowing buildings within herd, and

rooms within buildings) with selection of monitored farrowing units with known probability. The scheme is described in detail elsewhere (USDA:APHIS:VS, 1992; Tubbs et al., 1993).

2.1. Selection of states and herds

Eighteen states were selected for monitoring of sows and litters: 13 (Alabama, California, Colorado, Georgia, Iowa, Illinois, Maryland, Michigan, Ohio, Oregon, Tennessee, Virginia, and Wisconsin) because they were already actively involved in the National Animal Health Monitoring System (NAHMS) program; four (Minnesota, Nebraska, North Carolina, and Pennsylvania) because they were representative of other states with large swine populations; and one (Indiana) because of its large swine population and the expressed interest of its veterinarians. The selected states accounted for 62% of swine operations and 81% of hogs in the United States.

In each state, lists of farms were grouped by herd size (calculated as total inventory) in accordance with the size characteristics of the swine industry in the state. In states with large swine populations, herds were sampled approximately in proportion to the number of hogs. The targeted number of herds for sampling ranged from a minimum of 48 in states with few swine such as California and Oregon to 216 in Iowa. The primary outcome that influenced the number of herds to be sampled (and hence the number of litters to be monitored) was preweaning mortality. In states with large swine populations, herds were generally ineligible to participate if they expected less than ten litters to farrow during the following 3 month monitoring period. In states with relatively small numbers of swine herds, this restriction was not imposed. For herds with over 100 expected farrowings in the 3 month period, a random subsampling procedure (USDA:APHIS:VS, 1992) was used to select buildings and rooms for monitoring.

2.2. Questionnaires and data collection

The National Swine Survey was conducted in two phases and involved four questionnaires that were administered to the owner or manager of each herd in a consistent way (Fig. 1). Questionnaires were designed by NAHMS national staff in consultation with university swine specialists and epidemiologists.

In phase I, 3184 producers in the 18 participating states were randomly selected from a list of about 70 000 producers that was used for the USDA quarterly hog estimates (January 1989). These producers were contacted by National Agricultural Statistics Service enumerators and asked to participate in the study. Enumerators gave producers an overview of the survey, emphasizing confidentiality, the benefits of the program, and responsibilities of the participants. They obtained written informed consent in order to release the producer's name to USDA:APHIS:VS. Enumerators also completed the first questionnaire, the General Swine Farm Report (GSFR), for 1661 (52%) self-selected herds. This report included questions on management, inventory, sales and other descriptive information about each production phase. In addition, farrowing units for large herds were described so that NAHMS national staff could determine which farrowing facilities were to be monitored.

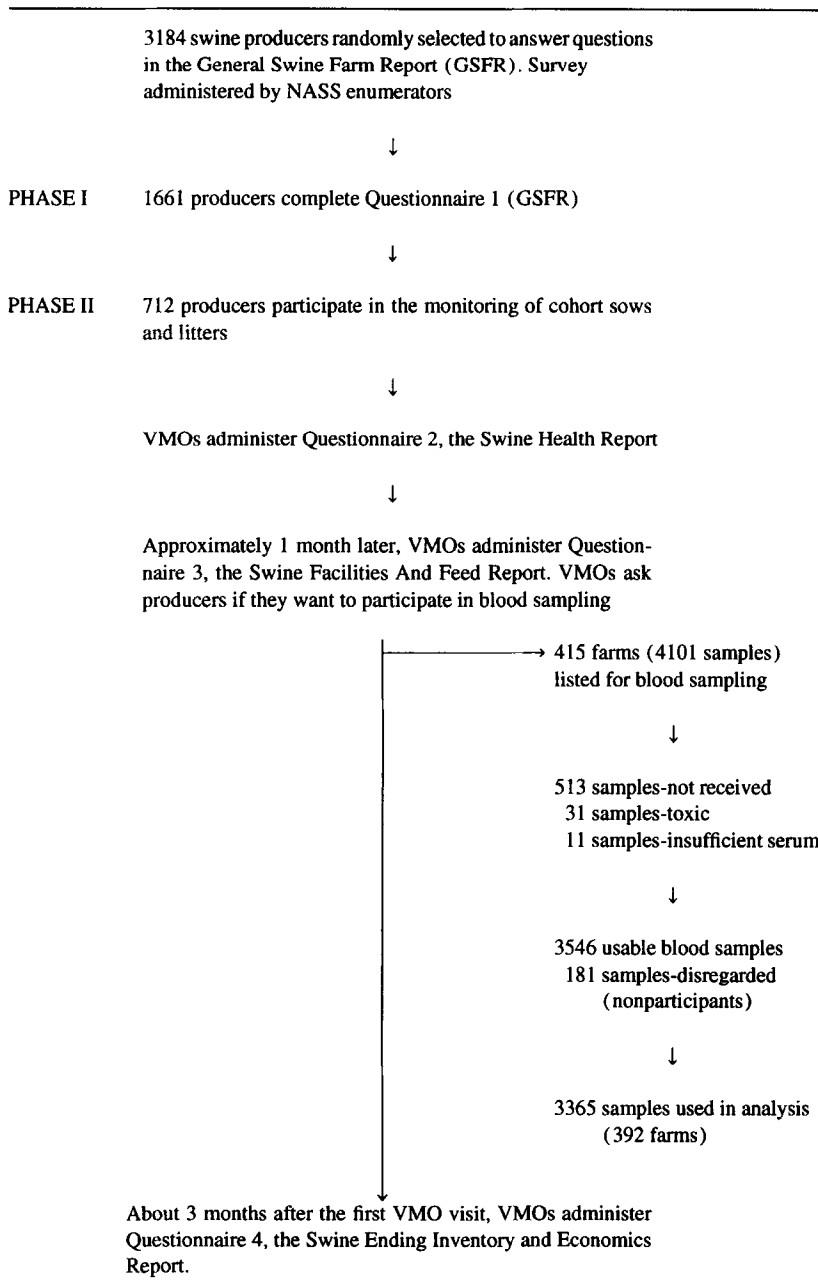

Fig. 1. Data collection and serologic sampling in the National Swine Survey, 1989–1990 (VMO, state or federal Veterinary Medical Officer).

In Phase II, producers were enrolled on a quarterly basis by state and federal Veterinary Medical Officers (VMOs) into the 3 month monitoring of sows and litters. Of 1661

producers that completed the GSFR, 712 (42.9%) agreed to participate and completed all remaining questionnaires (Fig. 1). The questionnaires included questions about herd demographics, swine health events on the farm in the preceding year including any history of TGE, vaccination and other disease control practices, biosecurity measures including pig movement and quarantine procedures, and access of possible animal reservoirs to the facilities. In addition to the required surveys, owners of monitored farms were requested to record treatments, and morbidity and mortality data for sows and piglets occurring during the 3 month follow-up. Diary cards used for data recording are shown in Tubbs et al. (1993).

2.3. Blood sampling

At the second visit, VMOs asked producers to take part in serologic testing for TGE, swine influenza, and encephalomyocarditis. Of the original 712 cohort herds, 392 (55%) agreed to participate. On each farm, blood samples (25 ml) were collected at a single sampling from the anterior vena cava or jugular vein of up to ten sows in the monitored farrowing buildings. At an assumed prevalence of at least 30% for the infectious agents of interest, sampling of five to ten breeding females provided at least 80% confidence of detecting at least one positive female given a perfect test (DiGiacomo and Koepsell, 1986).

Blood was shipped on ice, on the day of collection, to the USDA:APHIS:VS National Veterinary Services Laboratories (NVSL), Ames, IA, for testing for antibodies to TGE virus. Blood sampling was done over a year with 42 herds (10.7%) collected from December 1989 to February 1990, 119 (30.4%) from March to May 1990, 103 (26.3%) from June to August 1990, and 128 (32.6%) from September to November 1990. Because agreement was not reached about participation of VMOs in blood collection in Georgia, herds were not tested in that state.

2.4. Serum neutralization testing for TGE virus

Sera were diluted 1:4 with modified Eagle's minimum essential medium containing gentamicin (25 μg ml^{-1}) and amphotericin B (1 μg ml^{-1}). Diluted sera were heat inactivated at 56°C for 30 min and further diluted with the same medium (1:8 through 1:512 in 0.025 ml volumes) in 96-well tissue culture microtiter plates. An equal volume of Purdue strain TGEV, diluted to contain 300–500 $TCID_{50}$, was added to seven wells containing the diluted sera (1:8–1:512). The eighth well was a serum control. Plates were incubated for 1 h at 37°C. Swine testicle cells (0.15 ml) at a concentration of about 2×10^5 cells ml^{-1} were added to all wells. Plates were incubated for 5 days at 37°C in a CO_2 incubator. Serum neutralization (SN) titers were expressed as the highest dilution of serum that completely neutralized viral cytopathic effect. Sows with TGE titers of at least 1:8 were considered positive.

2.5. Definition of positive and negative herds

Serologic results were expressed as the percentage of TGE positive sows per herd. For evaluation of risk factors, those farms that had less than five samples tested ($n = 38$) were excluded from further analysis since the sample size was considered too small to have a

Table 1
Management and demographic factors evaluated in a study of TGE seropositivity in US swine herds, 1989–1990

Variable	Description of factor and corresponding strata
I. Demographics and TGE history	
SOWS	Female breeding herd size: ⩾500, 200–499, 100–199, 50–99, 5–49
OPRN	Type of operation: grower/finisher, feeder pig producer, breeder pig producer, farrow-to-finish
VACCN	TGE vaccination of breeding females: yes, no
HISTTGE	History of TGE in the last 12 months: yes, no
NRSWNIN3	Number of other swine farms within 3 miles of the farm: ⩾10, 5–9, 3–4, 1–2, 0
FRETGE	Herd considered free of TGE: yes, no
FARROW	Farrowing management: continuous, all-in all-out
SEASON	Season of blood sampling: fall, winter, spring, summer
II. Biosecurity measures	
A. Structural and personnel	
FENCOPER	Presence of a perimeter fence around the operation: yes, no
FTEMPFRW	Footbath requirement for employees in farrowing units: yes, no or not applicable
FTEMPBR	Footbath requirement for employees in breeding units: yes, no or not applicable
FTDLV	Footbath requirement for delivery personnel: yes, no or not applicable
FTLVHL	Footbath requirement for hired livestock haulers: yes, no or not applicable
FTVSTFRW	Footbath requirement for visitors in farrowing units: yes, no or not applicable
FTVSTBR	Footbath requirement for visitors in breeding units: yes, no or not applicable
BOOTEMP	Boots required for employees: yes, no or not applicable
BOOTDLV	Boots required for delivery personnel: yes, no or not applicable
BOOTLVHL	Boots required for hired livestock haulers: yes, no or not applicable
BOOTVST	Boots required for visitors: yes, no or not applicable
SHWREMP	Shower required for employees: yes, no or not applicable
SHWRDLV	Shower required for delivery personnel: yes, no or not applicable
SHWRLVHL	Shower required for hired livestock haulers: yes, no or not applicable
SHWRVST	Shower required for visitors: yes, no or not applicable
COVREMP	Coveralls required for employees: yes, no or not applicable
COVRDLV	Coveralls required for delivery personnel: yes, no or not applicable
COVRLVHL	Coveralls required for hired livestock haulers: yes, no or not applicable
COVRVST	Coveralls required for visitors: yes, no or not applicable
NRVSTOTH	Number of times someone from the farm visits another farm or market: ⩾5, 3–4, 1–2, 0
NRVSTTTH	Number of times someone from another swine farm visits the farm: ⩾5, 3–4, 1–2, 0
NRDLVON	Number of times someone delivers feed directly on-farm: ⩾5, 3–4, 1–2, 0
B. Pig movement and quarantine procedures	
NRTRKHIR	Number of times per month a truck was hired for trucking swine: ⩾5, 3–4, 1–2, 0
TRNFRMTR	Number of times pigs were transported to or from the farm in trucks owned by the farm in the last 3 months: ⩾5, 3–4, 1–2, 0
TRNSRCTR	Number of times pigs were transported to or from the farm on trucks owned by the source or destination point in the last 3 months: ⩾5, 3–4, 1–2, 0
TRNINDTR	Number of times pigs were transported to or from the farm by an independent trucker in the last 3 months: ⩾5, 3–4, 1–2, 0
NRTIMREM	Number of times per month pigs were moved from and returned to the farm: ⩾5, 3–4, 1–2, 0
NRSWNREM	Number of swine removed from and returned to the farm in the last 12 months: ⩾5, 3–4, 1–2, 0

Table 1 (continued)

Variable	Description of factor and corresponding strata
TTLSWNPR	Number of pigs purchased in the last 3 months: ⩾50, 26–50, 1–25, 0
SALEBARN	Number of pigs bought from a salebarn: >50, 26–50, 1–25, 0
BRDCMPNY	Number of pigs bought from a breeding company: >50, 26–50, 1–25, 0
PRDSPF	Number of pigs bought from a producer of SPF pigs: >50, 26–50, 1–25, 0
PRDNSPF	Number of pigs bought from a producer of non-SPF pigs: >25, 1–25, 0
TSTSTN	Number of pigs bought from a test station: >50, 26–50, 1–25, 0
FMSEP	Separation of breeding females upon arrival: yes, no, not applicable
MASEP	Separation of breeding males upon arrival: yes, no, not applicable
HLTSTSFM	Health test required for new breeder females: yes, no, not applicable
HLTTSTMA	Health test required for new breeder males: yes, no, not applicable
III. Possible reservoirs and carriers	
DOGSFRW	Dogs allowed in farrowing units: yes, no, not applicable
DOGSBR	Dogs allowed in breeding units: yes, no, not applicable
DOGSGST	Dogs allowed in gestation units: yes, no, not applicable
CATSFRW	Cats allowed in farrowing units: yes, no, not applicable
CATSBR	Cats allowed in breeding units: yes, no, not applicable
CATSFRW	Cats allowed in farrowing units: yes, no, not applicable
BIRDFRW	Birds with access to farrowing units: yes, no, not applicable
BIRDBR	Birds with access to breeding units: yes, no, not applicable
BIRDGST	Birds with access to gestation units: yes, no, not applicable
WLDFOX	Frequency of sighting wild fox: >4 times month^{-1}, 1 time month^{-1}, 1–2 times year^{-1}, never
WLDSTARL	Frequency of sighting wild starlings: >4 times month^{-1}, 1 time month^{-1}, 1–2 times year^{-1}, never

reasonable chance of detecting infection. Herds with one seropositive sow ($n=16$) were also excluded from the initial analysis because this group was considered to be the one where the true herd serostatus was most likely to be misclassified. The primary definition for a positive herd ($n=160$) was at least 20% seropositive (equivalent to at least two seropositive sows in the sample of five to ten) and for a negative herd ($n=178$) was 0% seropositive.

Because published data were not available on the individual sensitivity and specificity of the SN test, the optimal cut-off value (% positive samples) for aggregate interpretation could not be readily assessed. Consequently, we did several sensitivity analyses with different cut-off points (positive herds: at least 10%, at least 20%, or at least 50% positive samples; negative herds, 0% or less than 20% positive samples) to determine the robustness of the findings. We also included lack of history of TGE in the previous 12 months as an additional factor for designation of a negative herd.

2.6. Data management and analysis

Data were entered into a commercial database (R:Base for DOS, version 2.11, Microrim, Inc., Redmond, WA, 1987). Specialized data entry screens, reports, and data checking routines were designed by NAHMS national staff to minimize errors at all stages of data

collection and handling, and to ensure that the data were as complete as possible. Detailed descriptions of data management techniques are reported elsewhere (USDA:APHIS:VS, 1992; Tubbs et al., 1993).

Demographic and management variables that were hypothesized to be risk factors for TGE (Table 1) on the basis of published studies or speculation were extracted from various files in the database, merged into a single file with the TGE serologic results, and analyzed with BMDP (BMDP Statistical Software Inc., Los Angeles, CA, 1990).

Frequencies of five variables (type of operation, female breeding herd size, whether the farm manager/owner considered the herd free from TGE, previous history of TGE, and TGE vaccination history) that may have influenced a producer's decision to participate in serologic testing were compared between sampled and nonsampled herds by χ^2 test.

For participating herds, crude odds ratios (*OR*) and 95% confidence intervals (*CI*) were used to measure the strength of association between each risk factor of interest and the herd-level TGE serostatus (positive or negative). Factors with significant ($P < 0.05$) *OR*s in bivariable analysis were further evaluated by unconditional maximum likelihood logistic regression (Kleinbaum et al., 1982). However, based on evidence from previous studies, three variables that were potential confounders (season of sample collection (SEASON), TGE vaccination status of breeding females (VACCN), and number of females tested (NO–TEST)) were included in all models regardless of their significance. Other variables were allowed to enter models using a forwards-selection procedure (P-to-enter = 0.15 and P-to-remove = 0.10). Two-way interactions were tested hierarchically after determining the main-effects model. Adjusted *OR*s and 95% were calculated for factors included in final models.

3. Results

Herds that participated in the serologic testing for TGE were more likely to have reported a history of TGE in the previous 12 months and were less likely to have used TGE vaccines or claim freedom from TGE than nonparticipants. Participation, however, seemed to be independent of breeding herd size or operation type (Table 2).

Forty-five (11.5%) of the 392 blood-sampling participants reported a history of TGE in the year prior to the study. For 41/45 herds, a diagnosis was made by either the herd veterinarian and/or a laboratory, although the specific methods used to establish a diagnosis were not determined. Fifty-four (13.8%) owners or managers considered their herds free of TGE.

3.1. TGE seroprevalence

Although 4101 females from 415 farms were listed for testing for TGE antibodies, usable results were obtained only for 3365 females on 392 farms that had completed all questionnaires (Fig. 1). Of the 3365 samples (mean 8.7 per farm, median 10), 1177 (35%) tested positive with titers of 1:8 ($n = 82$), 1:16 ($n = 123$), 1:32 ($n = 157$), 1:64 ($n = 216$), 1:128 ($n = 183$), and 1:256 or over ($n = 416$).

Table 2
Demographic characteristics and TGE history of herds participating or not participating in blood sampling in the National Swine Survey, 1989–1990

Factor	Herds		*P*-value[a]
	Participants (%) ($n=392$)	Non-participants (%) ($n=320$)	
Female breeding herd size			0.89
⩾500	32 (8.2)	23 (7.2)	
100–499	173 (44.1)	151 (47.2)	
50–99	87 (22.2)	71 (22.2)	
1–49	100 (25.5)	75 (23.4)	
Operation type			0.16
Grower/finisher	2 (0.5)	1 (0.3)	
Feeder pig producer	81 (20.7)	51 (15.9)	
Breeder pig producer	14 (3.6)	6 (1.9)	
Farrow-to-finish	295 (75.2)	262 (81.9)	
TGE vaccination of breeding females			0.0001
Yes	86 (21.9)	112 (35.0)	
No	306 (79.1)	208 (65.0)	
History of TGE in previous 12 months			0.04
Yes	45 (11.5)	22 (6.9)	
No	347 (88.5)	298 (93.1)	
Freedom from TGE[b]			0.06
Yes	54 (13.8)	61 (19.1)	
No	338 (86.2)	259 (80.9)	

[a]*P*-value calculated by χ^2 test.
[b]Respondents were asked if their farm had been tested or examined such that they considered their herd free of TGE.

On a herd basis, 101 (25.8%) herds had seroprevalences of at least 80%, 79 (20.1%) had seroprevalences between 10% and 79%, and 212 (54.1%) herds had 0% seroprevalence (Fig. 2). Seropositive herds were detected in all states except Colorado, and four states (Illinois, Indiana, Nebraska, and Ohio) had more than 60% positive herds (Fig. 3).

3.2. Risk factors

Using the primary definition of positive and negative herds, significant crude *OR*s were obtained for five factors: female breeding herd size (SOWS), the number of swine farms within 3 miles of the farm (NRSWNIN3), the number of swine purchased in the last 3 months from herds that were not specific-pathogen-free (PRDNSPF), the number of times a truck was hired for trucking swine (NRTRKHIR), and the number of on-farm deliveries in the past 3 months (NRDLVON) (Table 3). Variables related to other biosecurity measures, potential reservoirs and carriers, and most pig and people movement variables

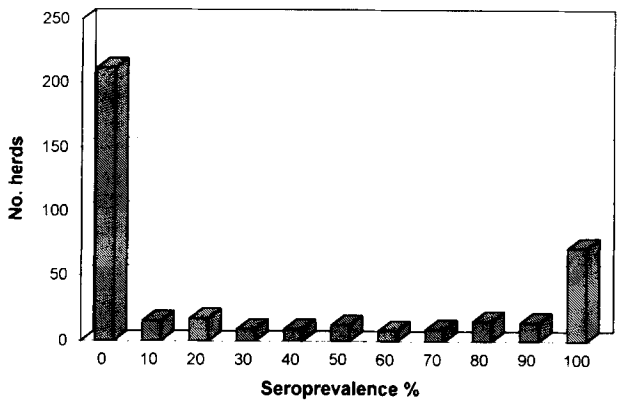

Fig. 2. TGE seroprevalence (%) for 392 herds in the National Swine Survey, 1989–1990. Seroprevalence calculated as the number of sows with titers of 1:8 or above divided by the number of tested sows.

were not significantly ($P > 0.05$) associated with herd TGE serostatus (data not shown) although we acknowledge that the frequency of some factors was low.

In the logistic regression analysis, significant adjusted *OR*s were obtained for SOWS and PRDNSPF after adjustment for each other and for SEASON, VACCN, and NO–TEST (Table 3). The variable NRSWNIN3, although not statistically significant ($P = 0.08$), remained in the final model using a *P*-to-remove of 0.10. The variables NRDLVON, NRTRKHIR failed to enter or remain in models that included SOWS primarily because of their positive association with the latter variable, and especially the category with at least

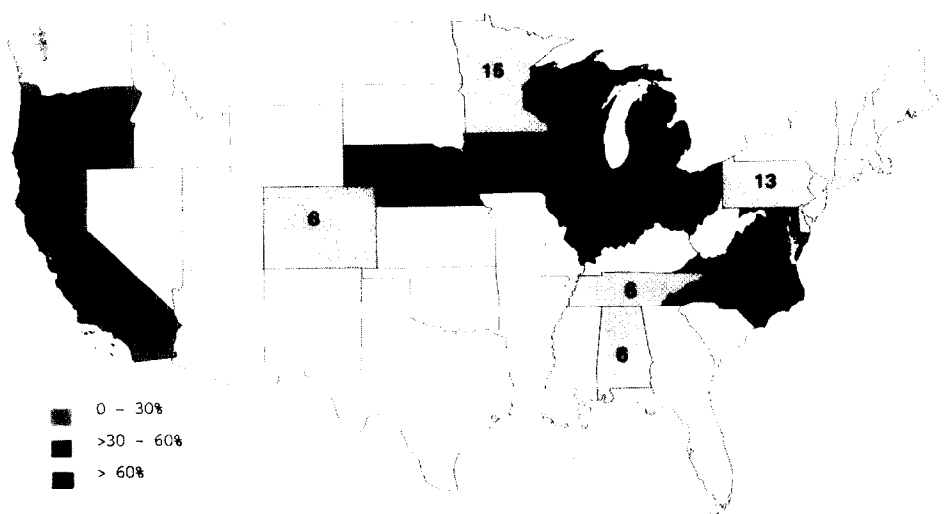

Fig. 3. Geographic distribution of number of herds tested for TGE in 17 states, National Swine Survey, 1989–1990. Seventy-eight herds with less than five sows tested or large herds identified on a regional basis only were not included. A herd was considered seropositive for TGE if at least 20% of sows were positive (titers 1:8 or more). Hatching indicates the percentage of seropositive herds in the state: dots, 0–30%; single hatching, over 30 to 60%; cross hatching, over 60%.

Table 3
Odds ratios (*OR*) and 95% confidence intervals (*CI*) for TGE serostatus of swine herds in the National Swine Survey, 1989–1990

Factor	No. herds	Crude *OR*	Adjusted *OR* (95% *CI*)
No. breeding females (SOWS)			
⩾500	30	4.27	4.86 (1.39–17.0)
200–499	72	1.93	1.64 (0.63–4.26)
100–199	92	1	1
50–99	80	1.01	1.09 (0.45–2.59)
5–49	64	0.55	0.68 (0.27–1.69)
No. swine herds within 3 miles (NRSWNIN3)			
⩾10	44	4.16	2.42 (0.85–6.87)
5–9	71	2.37	1.60 (0.65–3.96)
3–4	49	2.38	2.18 (0.83–5.13)
1–2	124	1.18	0.96 (0.42–2.16)
0	50	1	1
No. swine purchased from non-SPF herd (PRDNSPF)			
>25	24	3.65	3.86 (1.27–11.7)
1–25	70	1.03	0.97 (0.50–1.87)
0	244	1	1
No. times a truck hired (NRTRKHIR)			NI
⩾5	15	4.73	
3–4	23	1.08	
1–2	60	0.92	
0	240	1	
No. on-farm feed deliveries (NRDLVON)			NI
⩾5	46	2.42	
3–4	70	1.96	
1–2	135	1.21	
0	87	1	
Season when blood collected (SEASON)			
Winter (Dec.–Feb.)	34	1.74	1.13 (0.44–2.93)
Spring (Mar.–May)	107	1.44	1.04 (0.54–1.99)
Summer (Jun.–Aug.)	86	0.72	0.45 (0.21–0.93)
Fall (Sept.–Nov.)	111	1	1
TGE vaccination (VACCN)			
Yes	79	20.0	21.3 (8.95–50.7)
No	259	1	1
No. samples tested (NO-TEST)	338	1.24	1.02 (0.81–1.28)

Herds were designated as positive ($n=160$) if ⩾20% sows were seropositive and negative ($n=178$), if 0% of sows were seropositive. Herds with less than five samples tested were excluded from analysis.
Hosmer–Lemeshow χ^2 goodness-of-fit = 5.49, 8 d.f., $P=0.70$ for the model used to calculate adjusted odds ratios.
NI, variable did not enter or remain in model.
Odds ratio for NO-TEST is for a 1 unit increase in the number tested in the interval 5–10.

500 sows. In general, the adjusted *OR*s of variables tended to be smaller than crude *OR*s, but there were small increases in adjusted *OR*s for breeding herd size of at least 500 sows (4.3–4.9) and for purchase of more than 25 pigs from non-SPF herds (3.7–3.9). All two-way interactions among independent variables were not significant in the final model.

Of the variables of interest, SOWS had the strongest association with TGE seropositivity with herds with at least 500 sows at about 4.9 times higher odds of seropositivity than herds with 100–199 sows (the category with the median number of sows). There was some evidence of a positive dose–response relationship between the number of sows and the odds of seropositivity (but the 95% *CI*s for other herd size categories included 1). Of the potential confounders, VACCN had the strongest association ($OR = 21.3$) with seropositivity. Blood sampling during summer was associated with a reduced odds ($OR = 0.45$) of seropositivity, but the number of samples tested (range 5–10) did not influence ($OR = 1.02$) herd seropositivity.

Re-analysis of the data with different aggregate cut-off values of seroprevalence for classification of herds as positive or negative, and inclusion of TGE history did not markedly influence the variables selected in logistic regression models. Parameter estimates were mostly within $\pm 15\%$ of the estimates obtained with the primary definition (data available on request from authors).

4. Discussion

We identified two factors—female breeding herd size of at least 500 sows and purchase of more than 25 pigs from non-SPF herds in the last 3 months—that were associated with TGE herd seropositivity in logistic models. Because the duration of seropositivity on a farm was not known, we could not speculate whether the factors might have been associated with the risk of introduction of TGE, its persistence, or both outcomes.

Large herd size (at least 500 sows) significantly increased the odds of positive TGE serostatus compared with herds of 100–199 sows. This finding is consistent with another study (Pritchard, 1987) that also found a positive association between herd size and TGE recrudescence with the greatest risk in herds with more than 300 sows. Using data from Pritchard's study, we calculated that English herds with 101–300 and more than 300 sows were at 4.7 and 14.2 times higher odds, respectively, of TGE recrudescence than those with 100 sows or more. Herds of over 50 breeding pigs in Spain also had a higher prevalence of TGE than smaller herds (Cubero et al., 1993), but breeding herd sizes are typically smaller in Spain than in the United States or England. Demonstration of a herd size association is also consistent with the clinical impression of many swine producers and veterinarians in the United States that chronic TGE seems to occur more often in herds of more than about 200–500 sows. In large breeding herds, some susceptible females may not be exposed to infection during a primary outbreak of TGE (Pritchard, 1987). These females fail to transfer adequate colostral antibodies to suckling piglets which are often at the greatest risk of infection (Pritchard, 1982). A greater odds of TGE seropositivity might also occur in large herds because the absolute number of replacement females increases usually as herd size increases. Theoretically, a larger pool of susceptible females will facilitate circulation of the virus and hence the persistence of infection in the herd.

Other herd-size related management factors might also have influenced exposure to virus (Gardner et al., 1993). In large herds, there are frequently more contacts with potential sources of infection such as feed and pig transport trucks entering the premises. Indeed, the frequency of hiring a truck (NRTRKHIR) and the number of feed deliveries on farm (NRDLVON), were positively associated with large herd size when taken individually, but they failed to enter or remain in models after controlling for other variables. Uncleaned trucks or boots and other clothing used by truckers might be sources of virus for previously noninfected herds. Other unmeasured but important management factors that might occur more frequently in large herds, such as manure or fecal feedback, might also partially explain the herd size association. Pritchard (1987) also attributed part of the herd size association with TGE recrudescence to continuous farrowings and early weaning of piglets.

Most variables related to people and pig movement, except purchase of more than 25 non-SPF pigs, were nonsignificant after adjusting for other factors; but many of these management policies probably change with time in response to herd expansion plans, changing prices, and disease events. Herds that purchased more than 25 non-SPF pigs were about 3.9 times more likely to be seropositive to TGE than those that bought fewer non-SPF pigs. This result is consistent with the hypothesis that non-SPF herds are more likely to be infected with TGE than SPF herds, and therefore, pigs purchased from the former herds are more likely to be carriers of virus. Previous studies (Morin et al., 1974; Underdahl et al., 1976) have shown that TGE virus can be recovered from the intestine or lungs of feeder pigs for up to 4 months after infection. The TGE status of herds supplying pigs to the study herds was not known, but owners who in this study described themselves primarily as producers of breeding stock (SPF or non-SPF status was not specified) sometimes (5/14) had seropositive herds.

Our analysis failed to associate lack of quarantine procedures and health tests for purchased breeding pigs with TGE seropositivity. Less than 50% of producers who introduced breeding pigs 'health tested' new additions prior to entry into the herd. The type of health tests was not described in the database so we were unable to specifically determine whether introduced pigs were tested for TGE. When breeding pigs were quarantined on introduction, the duration was typically less than 40 days (USDA:APHIS:VS, 1992) which would be insufficient to prevent entry of TGE virus with untested carrier pigs. Another potential explanation for the lack of association was that most seropositive herds were probably chronically rather than recently infected. Pritchard (1987) concluded that TGE recrudescence and presumably a high level of seropositivity resulted from the introduction of susceptible pigs into an enzootically infected herd rather than the introduction of a carrier pig into an previously noninfected herd.

We found some evidence of an increased odds of seropositivity when there were more than two swine farms within a 3 mile radius of the sampled herd (NRSWNIN3). When farm density is high, there may be more movement of animals and people among farms in proximity, and manure and waste disposal practices may increase the risk of TGE spread. Swine herd density was also reported to be a risk factor for county prevalence of pseudorabies virus in Illinois (Austin and Weigel, 1992). Similar factors may be important in the transmission of both diseases although no evidence exists for long-distance airborne-transmission of TGE virus among swine herds as has been described for pseudorabies (Chris-

tensen et al., 1990) and porcine respiratory coronavirus (PRCV) infection (Henningsen et al., 1988).

The lack of statistical significance of structural biosecurity measures such as a perimeter fence and footbaths in production units, as well as boots, shower and coverall requirements, indicates that people probably are less important than carrier pigs in TGE seropositivity. Although recorded as occurring in some herds, these biosecurity requirements may not have been implemented consistently, and hence, these exposures also might have been misclassified. Because some factors such as footbath and showering requirements were infrequent (less than 10%), the power to detect significant differences in the *OR*s for some biosecurity variables was low. Although dogs, cats and starlings are possible intermediate hosts or reservoirs for TGE virus (Bohl, 1989; Saif and Wesley, 1991), we found no association between their access to facilities and herd serostatus.

As expected, herds that vaccinated against TGE were at significantly (21.3 times) higher odds of TGE seropositivity than nonvaccinating herds but reasons for vaccination were not recorded. A herd may have vaccinated because of a previous history of TGE or as insurance against severe clinical disease following introduction of TGE. Some evidence for the latter hypothesis is that 56 producers, who claimed freedom from TGE and reported no history of disease in the last 12 months, reported using TGE vaccine. Seropositivity in TGE vaccinated sows may have been caused by vaccination alone or by a combination of vaccination and field infection. Serum neutralization titers following vaccination are usually lower than postinfection titers and seldom exceed 1:16 in the absence of natural exposure (Hill, 1988). Because there was no unequivocal way to differentiate titers from vaccination from those due to natural exposure, vaccination status was included in logistic models. Also, the potential influence of vaccination on TGE seropositivity could have been better evaluated if the farm's TGE history over a longer period (3–5 years) were known and if the type of vaccine (killed or modified-live) had been recorded.

The use of the SN test for TGE serodiagnosis had some limitations. Serum neutralization titers tend to decrease rapidly even in previously infected sows. A TGE-infected sow can have a 1:32 titer that will decrease to less than 1:8 by her second farrowing (Hill, 1988), but in herds where TGE virus persists, at least some sows would probably have been recently exposed to virus and have higher titers. A more important limitation of the SN test was its potential inability to distinguish PRCV from TGE virus in some pigs and herds. Unlike enteropathogenic TGEV, PRCV infects the respiratory rather than the intestinal tract (Garwes et al., 1988; Van Nieuwstadt and Boonstra, 1992). Infection with PRCV induces antibodies that also neutralize TGE in vitro and, hence, the SN test may have failed to differentiate between TGE and PRCV infections. Other more specific tests, such as the blocking enzyme-linked immunosorbent assay (ELISA) (Callebaut et al., 1989; Van Nieuwstadt and Boonstra, 1992), may assist serologic differentiation of PRCV from TGEV. The blocking ELISA is more expensive, however, and for cost reasons could not be used for a national survey involving many samples.

Misclassification of herd TGE serostatus was not considered a major bias in the present study. Although estimates of the sensitivity and specificity of the SN test were not available, the distribution of serologic results (Fig. 2) was such that most herds (313/392) had 0% or at least 80% seropositive sows. Aggregate sensitivity, specificity, and predictive value calculations (Martin et al., 1992; Donald et al., 1994) indicated that misclassification of

herd TGE serostatus was probably not very great at the selected cutoffs (0% for negative herds, at least 20% for positive herds). These calculations (data not shown) were done assuming that the individual sensitivity and specificity of the SN test were both 0.9, that sensitivity and specificity correlations were 0, the mean prevalence in infected herds was 0.5, the intraherd correlation coefficient ranged from 0 to 0.9, that 50% of herds were infected, and that either five or ten pigs were sampled. Furthermore, by varying the aggregate cut-off value and including an additional criterion (lack of TGE history) in our negative group, conclusions did not change.

In some herds it is possible that TGE serostatus changed between data collection and blood sampling. Blood samples were usually collected at the second VMO visit, a month after the Swine Health Report was administered. The time lapse from survey to serologic sampling might have been sufficient time for TGE virus to be introduced into the herd, for recrudescence to have occurred, or for titers of some sows to have decreased below the positive cut-off value of 1:8.

Potentially, results of the study might be extrapolated to the entire population of US swine using sample weights as previously described for estimation of disease prevalence and the frequency of management factors (USDA:APHIS:VS, 1992). In the present analysis, however, participating and nonparticipating farms were shown to be different with respect to three TGE-related variables (history in the last 12 months, vaccination use, and freedom from TGE). Because of this selection bias and the lack of sampling in Georgia, population odds ratios were not calculated and inferences about risk factors were restricted to study herds.

Although the National Swine Survey database provided a good opportunity to evaluate many herd-level management and demographic risk factors that were associated with TGE seropositivity in the United States, some data that we needed were not available nor was it possible because of confidentiality to obtain the missing data retrospectively. The cross-sectional study design and lack of detailed questions on TGE history prevented us from determining how long herds had been infected, the reasons if any for TGE vaccination, and whether sows were vaccinated with live or killed vaccines. In addition, seropositivity in some herds may have been attributable to PRCV rather than TGE infection. Despite these limitations, the findings of the study support current knowledge of risk factors for TGE seropositivity. Large female breeding herd size (at least 500 sows) and the source and number of purchased pigs were found to be significantly associated with TGE seropositivity. The association with large herd size remained after many management variables were controlled for in the analysis.

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